THE EFFECTS OF ULTRAHIGH-PRESSURE WATERJET IMPACT ON HIGH EXPLOSIVES

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ABSTRACT

Alliant Techsystems tested the effects of ultrahigh-pressure waterjet impact on both PETN and TNT explosives. The pressure of the test was approximately 1 GPa (150 ksi) since this pressure generates the maximum water velocity, is the pressure limit of available equipment, and is the pressure at which water freezes at 25°C (75°F). PETN and TNT were chosen as representative of the range of explosives used in the industry. PETN is the most sensitive common secondary explosive, while TNT is a low-sensitivity explosive that makes up more than two-thirds of the military explosives used. The results of the tests show that neither PETN nor TNT reacts when impacted by waterjets at these pressures.

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INTRODUCTION

Background

Alliant Techsystems, formally the Defense Systems Group of the Honeywell Corporation, has pursued the use of waterjets on explosive materials for several years. Two other papers in this Department of Defense Explosive Safety Board Seminar deal with specific areas of our waterjet cutting experience: The first paper summarizes the parameters used for waterjet cutting of high-explosive ammunition, and the second paper summarizes the safety testing of waterjets on high explosives.

Definition of the Problem

This paper addresses the upper pressure limit of waterjet impact on high-explosive materials. As part of our safety investigations we identified several mechanisms for initiating explosives by waterjets. The most likely candidate for initiation of explosive materials was the effect of direct impact by high-velocity streams of fluid. To complete a credible safety analysis, our initial efforts were to identify other documentation in the field. Since waterjets are still an unconventional method of machining, however, there is a general lack of data on the effects of waterjets on explosives specifically. Some work does exist,[1] but at the relatively low pressure of 175 MPa (26 ksi) rather than at the 350 MPa (50 ksi) pressures that commercial waterjet equipment operates.

Approach

Because the most likely candidate for initiating the explosives was the effect of waterjet impact, we decided to use the highest possible pressure in a standard Bruceton test to establish the actual 50 percent fire point. The maximum pressure obtainable at a continuous flow was approximately 1 GPa (150 ksi). This pressure was finally agreed upon because it is the highest pressure currently available, it generates a water stream traveling at nearly the sonic limiting velocity of water—1475 m/s (4900 f/s)[2]—and it is the pressure water freezes at 25°C (75°F), a condition which creates an upper limit for any "worst case" runaway pump scenarios.

Once the pressure was chosen, the components were assembled to perform the test. A statistically large sample of 50 shots for each explosive was planned in order to prove the effects of waterjets on the explosives.

APPARATUS AND PROCEDURE

Test Setup

We investigated the three domestic vendors of high-pressure waterjets and identified only one machine that was capable of producing the necessary pressure of 1 GPa (150 ksi) for greater than two seconds. Since this ultrahigh-pressure machine was not transportable, the testing was

[1]Summers, D., and Worsey, P., *The Use of High Pressure Water Jets to Wash Out Explosives*, Proc. 6th Int. Conf. on Erosion by Liquid and Solid Impact.

[2]Hendricks, R., et al., *WASP—A Flexible FORTRAN IV Computer Code for Calculating Water and Steam Properties*, NASA Technical Note D-7391, November 1973.

performed at the Ingersoll-Rand facility in Baxter Springs, Kansas. The ultrahigh-pressure waterjet machine was fortunately located in a test cell that had 30 cm (12 in.) thick concrete walls suitable for our explosive testing.

The ultrahigh-pressure waterjet pump was actually two pumps and a large, custom-made accumulator built for this test sequence. Although the ultrahigh-pressure system (Figure 1) was capable of achieving our required pressures, the unit normally operated at much lower levels. This situation caused concerns over how long the system would survive operating at the requested pressures. Piping for the system was specially manufactured, two-component, 1.3 mm (0.05 in.) bore tubing with a 19 mm (0.75 in.) outside diameter as shown in Figure 2. Fittings for the system were standard 25 mm (1 in.) high-pressure compression fittings.

No one was allowed in the test area during pressurization due to the high pressures the system utilized. At these pressures the liquid mixture becomes a compressible material and the tubing expands enough to store a significant amount of energy. A special mixture of propylene glycol and glycerin was used as the working fluid instead of water since water would freeze if the system temperature dropped below 25°C (75°F).

A special pressure transducer was obtained and custom fittings were fabricated to provide an accurate reading of the pressures going into the test chamber. Data from this pressure transducer was recorded on a Nicolet recording oscilloscope and also displayed on a peak-holding digital readout. These recorders supplemented the existing recording device used for the normal operation of the ultrahigh-pressure pump.

As an additional safety precaution inside the concrete walls of the test cell, we constructed an explosive test chamber (Figure 3) of 13 mm (0.5 in.) steel plate and proof-tested the chamber at 200 percent surcharge. No distortion or damage was done to the chamber by the proof tests. Inside the chamber was mounted a specially made, pneumatically controlled high-pressure valve manufactured by Harwood Engineering and rated for 1 GPa (150 ksi). The valve was placed close enough to the orifice, to minimize the pressure drop from piping friction but still be protected behind a steel blast shield. Pressure drop across the valve was measured by Ingersoll-Rand technicians at 68 kPa (10 psi). The system used a 0.13 mm (0.005 in.) orifice (Figure 4) for all tests in order to maintain fluid pressure in the system. Due to the ultrahigh pressures involved, diamond orifices were used and replaced when worn or damaged.

The explosive samples were set into a custom holder (Figure 5) for the actual impact shot. This holder allowed the fluid to impact the explosive and capture the liquid for later analysis by our laboratories.

Test Procedure

To perform a statistically credible test, 50 explosive samples were tested of each explosive material. The materials selected for the test were Mil-Spec pressed PETN and cast TNT explosive samples. Our other waterjet safety tests had referenced each test sequence against a cast TNT standard. We also used the same TNT reference in this test to retain traceability. The PETN was chosen since it is considered the most impact-sensitive secondary high-explosive material and, if the TNT failed to initiate at the pressures that we were attempting, the PETN might still react within that pressure range.

The explosive materials were loaded individually into the test chamber and both the chamber and the test cell sealed. Once the area was cleared of personnel, the ultrahigh-pressure system started the pressurization sequence. Several minutes later the system finally reached the maximum achievable pressure and the data recorders were activated. Some variation occurred as the system gradually degraded due to the effects of the high pressure. When the system failed to achieve the target pressure, the test was aborted and the system was dumped into a safety tank. The source of the failure was identified, corrected, and the test sequence restarted.

Once the system was at its maximum pressure, the explosive technician authorized the shot and the high-pressure valve was actuated. The system pressure lasted only a few seconds before the pressure bled down below the test levels. The remaining liquid was then dumped to the safety sump. The explosives were visually analyzed immediately after the test shots and then packaged for return transportation to our laboratories. Photographs of the samples were taken and sent for advance examination by our laboratory scientists. All liquid retained in the test holder and residual explosive materials were packaged in prepared sample bottles and sent immediately back to the laboratory for analysis. In addition to the explosive samples, virgin liquid and untouched explosive samples were also taken as control samples for laboratory comparison.

RESULTS

We successfully tested 50 of 51 samples of PETN and 51 of 53 samples of TNT at the maximum pressure of the machine. No reaction, identified either visually or by chemical analysis, occurred as a result of the action of ultrahigh-pressure fluid impact on either PETN or TNT. The actual pressures measured at the valve, as shown in Figure 6, ranged from a minimum of 0.82 GPa (120.6 ksi) to a maximum of 1.02 GPa (149.9 ksi). The average test pressure for PETN was 0.97 GPa (142.6 ksi) and for TNT was 0.94 GPa (137.6 ksi).

Of the 50 PETN tests, only one "no-test" occurred due to a dislocated target; this test was not counted in the total. Two of the TNT tests were invalidated due to valve problems and these were deleted from the data. We had anticipated such a problem and quickly replaced the defective valve with a standby valve.

During the tests several diamond orifices failed due to plugging by ferrous particles. These particles may have been from either piping contamination or an incipient failure of some internal pump component. One of the plumbing connections failed during the test without major incident. As we tried to pressurize the system, we found that we could not maintain pressure. The system was "dumped" and the piping inspected. The failure was easily spotted and the tubing replaced. The tubing used was a special two-part, high-pressure tubing manufactured specifically for the pressures at which we were operating. The outer part of the tubing is swaged over an inner tube forcing the inner tube into compression. The failure, as shown in Figure 7, was caused by the swaged inner liner of the tubing being extruded by the operating pressure and pushing apart the connector.

CONCLUSION

The testing of both PETN and TNT at pressures of 1 GPa (150 ksi) was successful. It demonstrated that these explosives were safe to cut with a waterjet at these pressures with a single tailed safety interval of 96 percent at a statistical confidence interval of 95 percent. The safety of these tests confirm the impact model that we developed and are presented in the second paper of these proceedings.

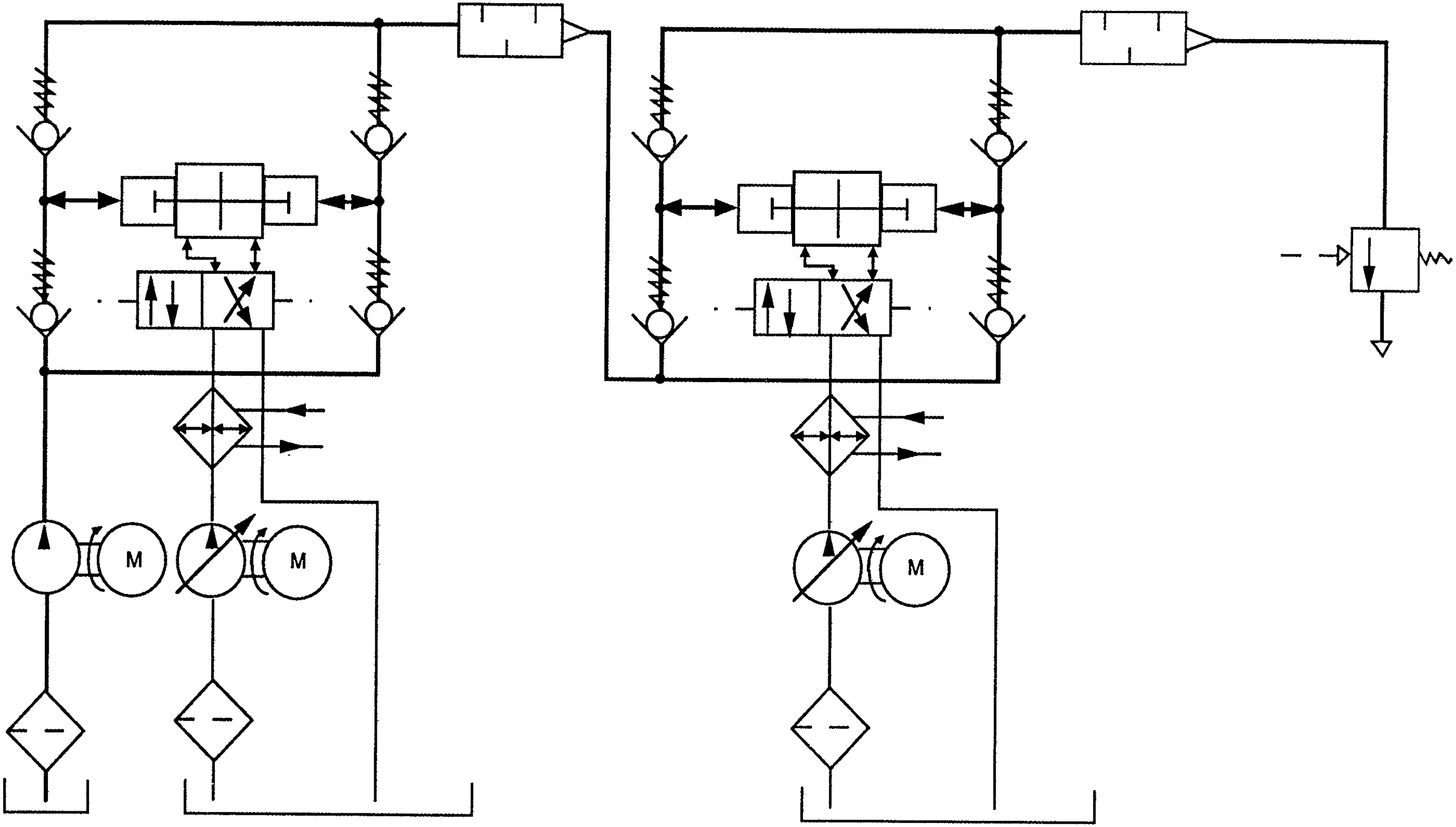

Figure 1. Ultrahigh-Pressure Waterjet Pump System Schematic

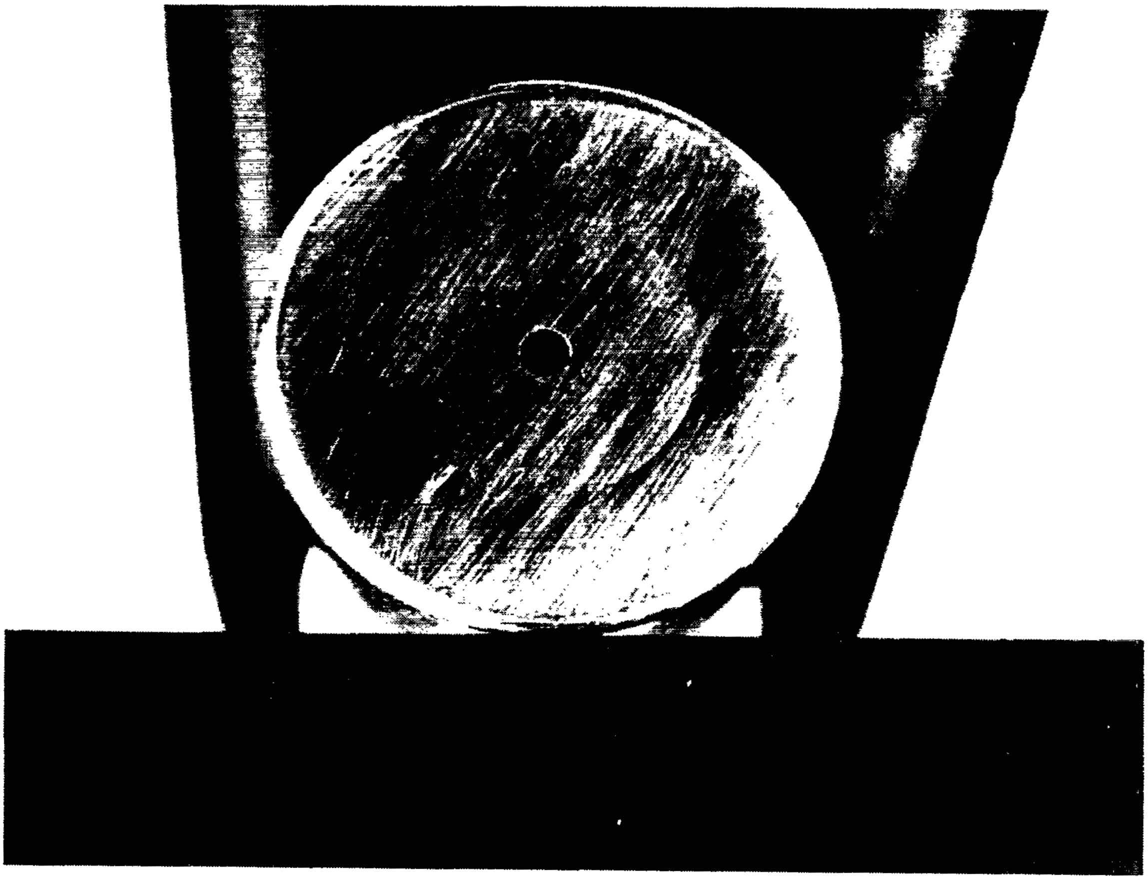

Figure 2. High Pressure Tubing

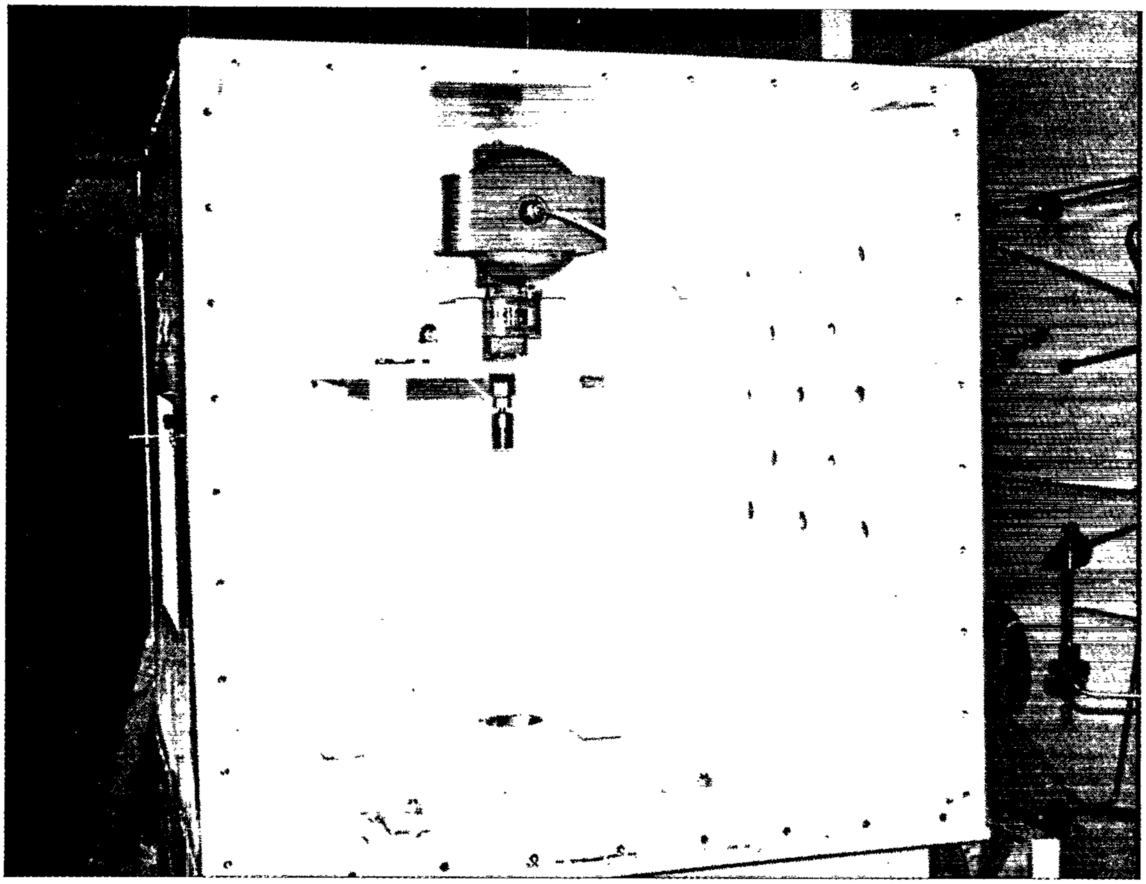

Figure 3. Explosive Test Chamber

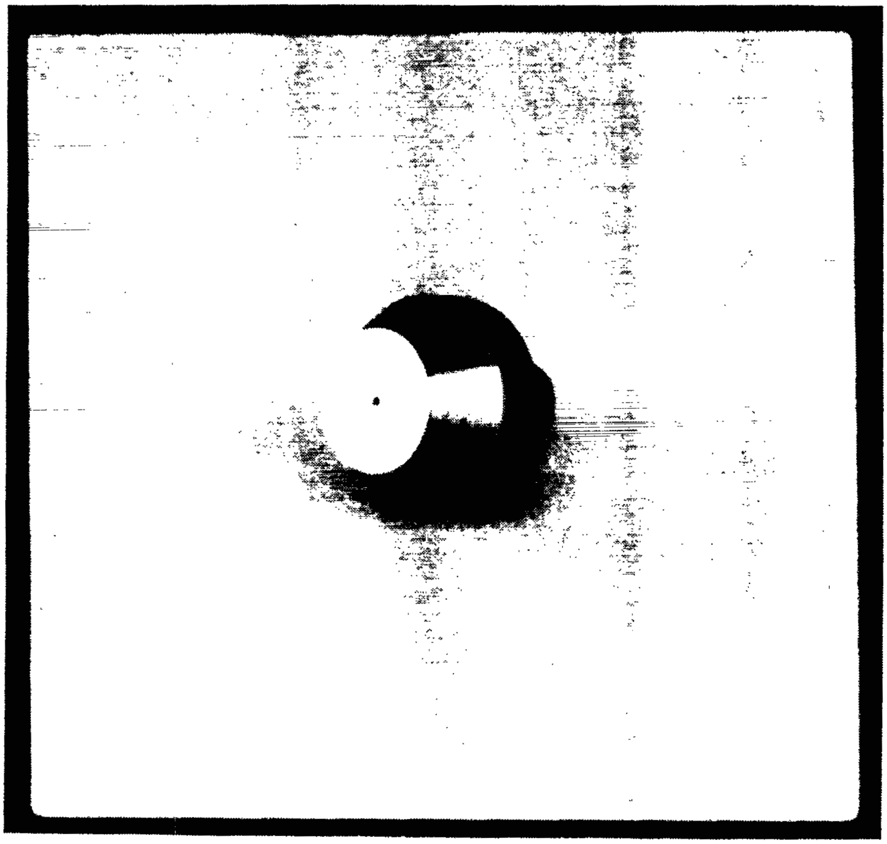

Figure 4. High Pressure Orifice

Figure 5. Explosive Sample Holder

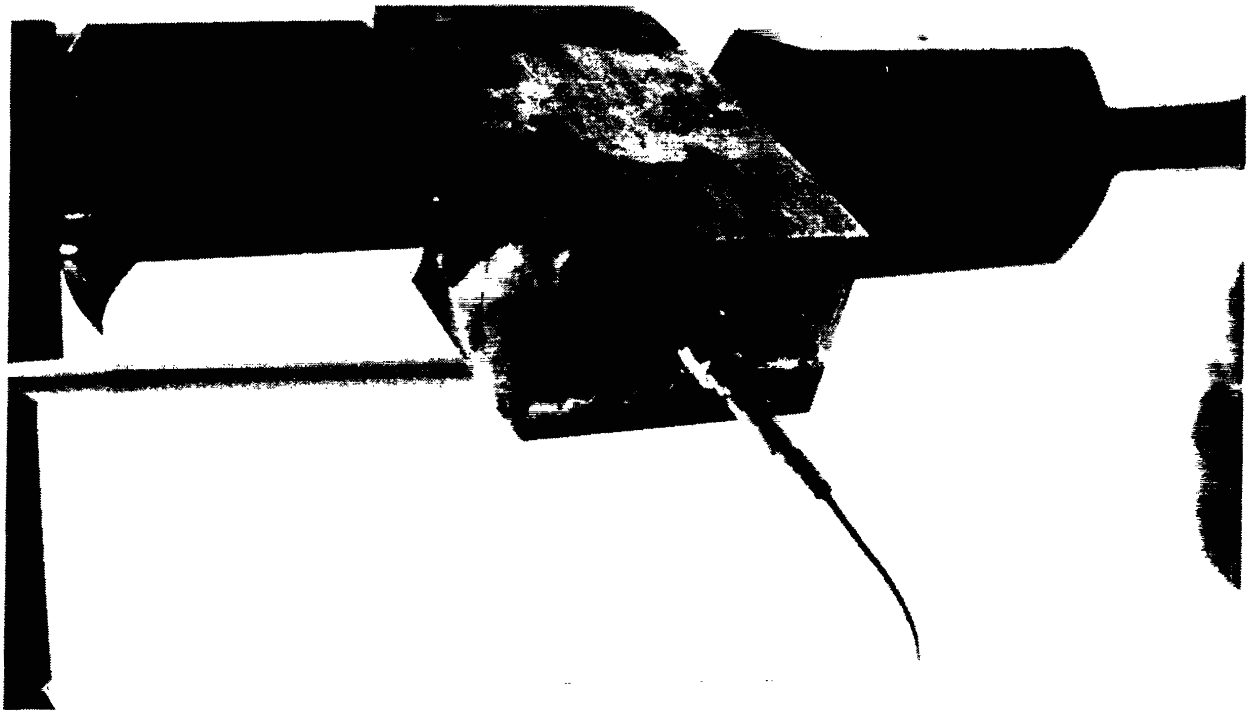

Figure 6. Ultrahigh-Pressure Transducer

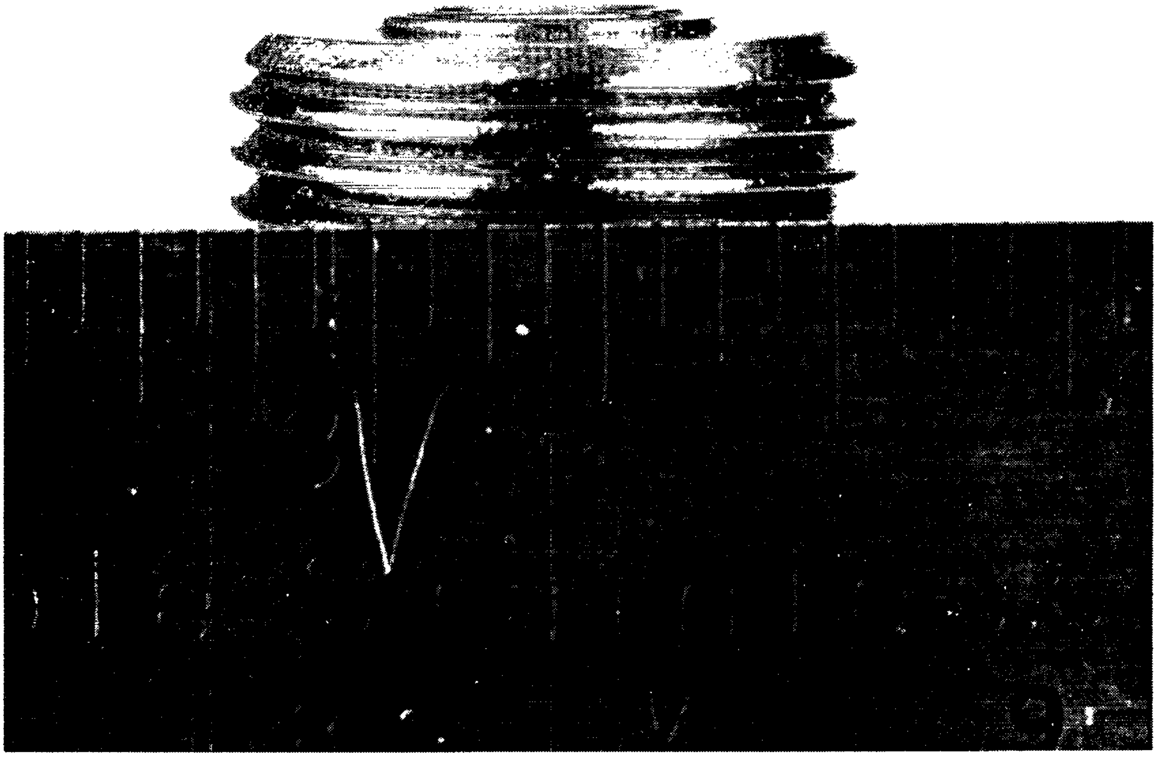

Figure 7. Tubing Failure